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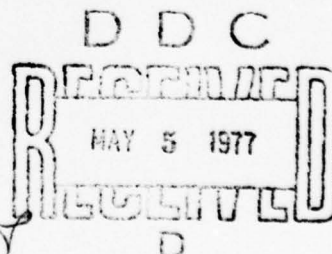
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VACATE: A MODEL FOR PERSONNEL INVENTORY PLANNING UNDER CHANGING

MANAGEMENT POLICY

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ABSTRACT

A model is described for projecting inventories of enlisted Naval personnel expected to result from management policy aimed at controlling the size and experience mix of the inventory. The effects of policy changes are modeled as changes in flow probabilities into and through an inventory partitioned along dimensions of experience level (length of service) and time until end of obligated service. An example is presented which illustrates several innovative features of the model which lead to an improved planning capability. Continuing efforts to improve the model are discussed.

INTRODUCTION

The VACATE (VAriable Continuation rATE) model projects the enlisted personnel inventory expected to result from selected management policies. It accounts for the effects of policy changes estimated from previously developed relationships, on attrition and personnel allocations. The effects of policy changes are shown in terms of changes in continuation rates and the redistribution flows in the inventory. This capability is not available in any other known model. *The model projects personnel inventories*

The model was developed as part of the Enlisted Manpower Personnel Planning System (EMPPS) study, which is an attempt to help the Navy improve its planning and programming of enlisted manpower, personnel and training. Manpower programming is a process that specifies the number of personnel which must be accessed, trained and retained in the skilled inventory to meet future requirements.

An inventory projector, such as VACATE, is a useful tool in this process since it allows personnel managers to measure the expected effects of their policies for controlling the size and experience mix of the inventory.

In the sections that follow, existing methods for projecting inventories are described, and their shortcomings noted. Then, the VACATE method is presented, with emphasis on its improvements. Preliminary results of tests of the VACATE model are then shown, which illustrate how it may be used to assess the impact of management controls which could be applied for meeting personnel requirements. The final section highlights continuing efforts to improve the model.

INVENTORY PROJECTION METHODS

Personnel inventories are usually projected by

o   partitioning a base, or starting inventory, into homogeneous groups,

o   applying separate annual continuation rates to each group (aging the inventory) and

o   adding new additions which survive until the end of the year.

If projections covering several years are desired, the process is repeated the appropriate number of times.

Projection procedures differ essentially according to the method of partitioning. Models currently in use in the Navy partition each rating or skill group in three ways:

o   31 Length of Service (LOS) cells

o   six time-until-end-of-active-obligated-service (EAOS) and three experience level (careerists, first termers, unskilled) groups

o   seven or nine paygrade groups.

Some groupings (partitions) are more homogeneous with respect to continuation behavior of its members than others, and as a result, the associated continuation rates tend to be better descriptors of continuation for the group. Rates which apply to paygrade alone lack credibility because of the relative low level of homogeneity as compared to LOS groups. Both LOS and EAOS partitioning methods provide acceptable results and are in general use.

VACATE integrates these two preferred methods by partitioning across both LOS and EAOS. In addition to this innovation, VACATE employs an enlistment/reenlistment/survivor redistribution feature, and also a training pipeline output feature not included in any other model.

The development of VACATE was motivated by the need for a model capable of assessing the independent effects of policies aimed, for example, at: (1) user specified experience levels (i.e., any LOS groupings); (2) changing flows through the training pipeline (A school and OJT); (3) changing the contract mix of entering co-horts; and (4) increasing reenlistment rates. No existing inventory projection models have all these features.

VACATE Methodology

The VACATE model treats one skill group (Navy rating) in the trained inventory at a time.[1] The base inventory is separated into 31 LOS groups, and each of these is spread across seven EAOS (time until end of enlistment contract) cells. The total in each cell is then aged by first, adjusting the total downward to reflect pro-jected attrition, and second, redistributing the remainder to new EAOS cells with the next LOS. The end inventory is then adjusted for projected net surviving lateral transfers to or from other skills. Next, projected prior service reenlistees and new additions from training pipelines are added. This inventory becomes the begin in-ventory for the next year's projection.

In the following three sections we shall discuss, in greater detail, the flows out of the inventory (attrition), through the in-ventory (redistribution), and into the inventory (training pipelines, lateral transfers and broken service gains).

Attrition

Attrition from the inventory is modeled by multiplying the number of men in each LOS/EAOS partition in the begin inventory by the fraction expected to survive to the end of the period (one year later). These fractions, or survival probabilities, are what VACATE uses for continuation rates.

During each cycle of VACATE projections, the identical set of LOS/EAOS survival probabilities are applied to the begin inventory to determine the number of survivors. We are therefore assuming that

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[1] When we refer to an inventory we are including only designated personnel. Undesignated strikers are not attributed to skill groups.

continuation behavior is a stationary process during the period of
projection, i.e., the survival probabilities are constant from year-
to-year. This is a reasonable assumption where the determining fac-
tors of continuation behavior, such as bonuses, and early-out policy
for example, remain stable.

Redistribution

VACATE uses a 7 x 7 EAOS redistribution matrix for each LOS
group to place continuers from their current EAOS cells into new
EAOS cells at the beginning of the next period. Each 7 x 7 matrix
represents transition probabilities of flowing into any EAOS cell
from each of seven EAOS cells as an individual moves from his cur-
rent LOS cell to the next one at the end of the year.

The first upper diagonal in a redistribution matrix represents
the normal flow. Generally, personnel move from EAOS i in year j to
EAOS i-1 in year j+1. Entries above the first upper diagonal indi-
cate multiple EAOS reductions in a year, resulting perhaps from
failure to complete a school which required an extension. Entries
in the main diagonal and below represent a mixture of reenlistments
and extensions. This redistribution aspect of VACATE is a key feature
which differentiates it from other methodologies. The impact of the
redistribution feature can be seen by comparing two years of VACATE
projections to projections which don't include this feature but
operate on LOS-only information.

Figure 1 illustrates how a cohort of 100 men flows through the
inventory for two successive periods. In this example, we follow
the cohort from LOS 4 through LOS 5, and for simplicity, assume that
the continuation rates for LOSs 4 and 5 are the same. Flows are
shown by LOS and EAOS and LOS alone. Note that the continuation
rates for LOS-alone are computed as a weighted average across the
EAOS dimension in the starting inventory. Projections for the LOS-
alone model are obtained by multiplying the starting cohort size by
the continuation rate, .71, to obtain the first projection of 71
men, and then multiply these survivors by the continuation rate for
their new LOS, also .71, to obtain the second projection of 50.

VACATE projections for the first period are the result of
multiplying the number of men in each EAOS cell by their respective
continuation rates and then summing across the EAOS dimension to
obtain the total in the surviving cohort, which becomes the starting
cohort for begin period two. Note that the two methods give identi-
cal results, in terms of the size of the first surviving cohort.
This is to be expected because the continuation rate used by the LOS-
alone model is a weighted average of the VACATE rates, as mentioned
before.

EAOS			VACATE				
	1	2	3	4	5	6	All
Start inventory (LOS 4)	50	5	35	5	5	5	100
x							
Survival Prob.	.50	.80	.86	.80	.80	.80	.71
=							
End inventory (LOS 4)	(25)	4	30	4	4	4	71
Begin inventory (LOS 5 -- redistributed from End LOS 4)	4	30	4	(15) + 4	4	(10)	71
x							
Survival Prob.	.50	.80	.86	.80	.80	.80	.79
=							
End inventory (LOS 5)	2	24	3.5	15.2	3.5	8	56.2

LOS ONLY

Start Inventory (LOS 4)	100
x	
Survival Prob.	.71
=	
End Inventory (LOS 4)	71
x	
Survival Prob.	.71
=	
End Inventory (LOS 5)	50.4

Figure 1: Effect of Redistribution in Two-Period Projection

After VACATEs survivors from the first period are redistributed into <u>new</u> EAOS cells (e.g., 60 percent of the reenlistees from EAOS 1 become 4 Y.O.s and go to EAOS 4, and the remaining 40 percent who are 6 Y.O.s go to EAOS 6) the reason for differences in projected inventories which will result at the end of period two becomes apparent. The redistributed cohort is no longer spread in the same proportion across EAOS as in the starting inventory. This redistribution results in a new set of weights for computing composite continuation rates. In this illustration, VACATE projects a larger inventory after period two because a larger proportion of redistributed people are now in EAOS cells having higher survival probabilities. The new composite continuation rate resulting after period two is 56 divided by 71, or .79. Thus, VACATE projects a composite continuation rate of .79 while the LOS-only composite rate remains unchanged at .71.

Training Pipeline Flows

Another innovative feature of the VACATE model is the explicit accounting for the time it takes to get through the training pipeline, whether training is formal or on-the-job.

In the Navy, personnel become members of the trained inventory at the time they become "designated" in one of the 82 general skill categories, called ratings. Designation can result from completion of formal or informal (OJT) training. The flow of designated personnel into a rating appears predominantly in the first five LOS groups. For the most part, those who become designated in LOS 1 and 2 are graduates of formal training, and those entering into LOS 3 and above are a mixture of formal and informal training.

VACATE estimates pipeline flows into the trained inventory by the following method. Here we shall consider a combined A-school, OJT pipeline. The number of men appearing for the first time (less lateral transfers and broken service gains) in LOS cells 1-5 are measured for the current year. Those who appear in LOS 1 are A-school (formal training) graduates who have entered the inventory from allocations to the training pipeline in that year. It follows that those entering in LOS 2 were from allocations in the previous year; and so on. Note that not all enter in the year they were allocated. From this LOS distribution and the historical allocations, we know the proportion of an allocation i years ago that appear in the current inventory in LOS $i+1$.

The following notation is helpful for describing the entire process.

Let:

i indicate the year of the allocation.
$i = \{-4, -3, \ldots, 3\}$

$$j = \text{LOS } j = \{1, 2, \ldots, 5\}$$
$$n_i = \text{number allocated in year } i$$
$$X_{ij} = \text{number entering the inventory in } \text{LOS}_j \text{ during year } i.$$

Then

$$X_{ij} = f_j \cdot n_{-(j-i-1)}$$

The resulting fractions, labeled f_j, are assumed to be representative of how any given allocation is distributed, both historically and in the future under a constant policy.

Lateral Transfers and Broken Service Gains

Two additional sources of inputs to the trained inventory are lateral transfers (in) and broken service reenlistees (gains). These individuals differ from training pipeline inputs in a number of ways.

While pipeline personnel were undesignated (i.e., unskilled) prior to entering the rating, lateral transfers were previously designated in another rating, usually requiring similar technical skills to perform the jobs of the rating into which they transfer. Broken service reenlistees are characterized as having been previously trained and designated in a rating, left the Navy for a period of time, then reenlisted and reentered the rating at some later time, usually without the need for extensive retraining.

Unlike inputs from the training pipeline, laterals and broken service gains are _not_ the result of _previous_ allocations. Rather they all enter the inventory during the same year they were allocated. Broken service gains tend to reenter due to extra-Navy factors, e.g., unemployment. Also, the magnitude of the lateral transfer and broken service inputs tend to be small relative to the total number of inputs. While training pipeline inputs represents about 20 percent of the inventory, these other inputs account for less than one percent.

DATA BASE

In the previous section we have described how VACATE models flows through the personnel inventory. We will now discuss the data base on which the model rests.

The source of data for generating the inventory flow measures is the Enlisted Master Record (EMR) personnel tapes obtained from

BuPers (the Bureau of Naval Personnel). These tapes list all in-
dividuals who are on active duty at a point-in-time.[1]

The basic procedure involves comparing two sets of EMRs dated
12 months apart. Individuals are tracked during the 12-month inter-
val and personnel appearing on one or both files are identified.
Individuals who appear on both files are "continuers." Those appear-
ing on only the first file (period 0) are losses, and those appear-
ing only on the second file (period 1) are gains. Various procedures
are applied to identify rated individuals, training pipeline flows,
lateral transfers and broken service reenlistees. Individuals are
sorted into LOS and EAOS cells, and supporting statistics are then
computed.

MODELING CHANGES IN POLICY

The discussion of how inventory flows are modeled by VACATE
pointed out a number of processes which are treated as stationary
during the period of projection. What are the implications for the
VACATE user if one or more of these processes such as continuation
behavior, EAOS redistributions or pipeline flows are expected to
change? The answer lies in the nature of the change.

Changes in flows through the inventory are accommodated by an
adjustment to VACATE's data base. For example, changes in reenlist-
ment bonuses for first termers should influence both continuation
behavior and the mix of reenlistment contracts. This implies a
change in continuation rates for those at the reenlistment point
(EAOS 1), mainly in LOS 4 through 6; and in the redistribution of
reenlistees into new EAOSs. Such a policy would be modeled by in-
creasing the continuation rates by expected elasticities of the bonus
in LOS 4, 5, 6 EAOS 1, and by changing the transition probabilities
in the "receiving" EAOS vector to reflect the new contract mix
specified by the policy.

Thus, two previously stationary processes (continuation and
redistribution) have shifted but the shift is quantifiable, and
appropriate changes are made by the model which maintain the sta-
tionarity at a new level during the "life" of the policy. A change
in a stationary process is therefore incorporated in VACATE by
adjusting a data set.

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[1]The EMRs maintained by BuPers contain individuals who may have
left the Navy 90 to 120 days prior to the creation of the tape.
An extract of those complete EMRs was prepared which excludes all
individuals in a non-active status, as well as reservists and
deserters.

In the next section, we will illustrate several examples of how VACATE could be used to address policy issues and how adjustments to the data sets associated with the policies are made.

EXAMPLES

These examples are presented to illustrate how policies are modeled by VACATE. Results presented here were derived during preliminary testing of the model and do not represent recommendations. In this example, only one skill group is treated.

Shown below are projected requirements and allocations to the inventory, for the rating over the next 8 years (FY 76T - FY 83):

	1976T	1977	1978	1979	1980	1981	1982	1983
Total required	24211	24792	24898	25347	26015	25605	25605	25605
Total projected	23701	24185	24007	23823	23745	23609	23763	23888
Training allocation	5990	5946	5357	5321	5645	5600	5600	5600

The inventory projections were made by the VACATE model using continuation rates and redistribution matrices for the rating which were achieved in FY 76. Allocations to training were made in accordance with current rating input plans. Other inputs were added from broken service reenlistments and lateral transfers in about the same amounts that were actually realized during FY 76. The vector used to model flows into the rating from a given allocation to the training pipeline is shown below:

$$f_i = [.44 \quad .25 \quad .06 \quad .05 \quad .01]$$

Note that 19 percent of a cohort which is allocated is expected to attrite from the pipeline, i.e., will never enter the rating.

Manning in the rating, as of the end of the base year (FY 76T) was at 98 percent for the total rating, and the career force (LOS 5 and above), shown below was manned at 89 percent.

	1976T	1977	1978	1979	1980	1981	1982	1983
Career required	13075	13389	13445	13688	14049	13828	13828	13828
Career projected	11707	11663	11387	11734	11508	11541	11552	11523

Manning in both categories is projected to get worse, under current policy, if the current input plan were followed.

The manager responsible for this rating might wonder what he could do to change this worsening trend in manning. We will show how VACATE might be used to evaluate the effects of several policy options which could be implemented to increase the total in the rating and the career force. Three policy options are considered: (1) application of a large bonus aimed at increasing first term reenlistments; (2) making the bonus contingent upon signing a 6-year reenlistment contract, and (3) requiring a 6-year enlistment contract for A-school.

For the policy options being considered in this example, allocations to the training pipeline were held constant.[1]

While the rating manager may desire to project inventories which would result from applying different combinations of options, we will only illustrate the marginal effects of changes in each option.

<div align="center">Reenlistment Bonus Option</div>

VACATE was used to project the inventory which would result if the largest bonus allowed were applied to those in LOS 4, 5, and 6 in EAOS 1 and 2 over the next 7 years. The changes in continuation rates induced by the bonus were taken from references (a) and (b). Increases as great as 10 percentage points occurred within LOS cells 4 to 6.

The impact of this change in rates on projected inventories is shown below in terms of percentages of requirements:

	1976T	1977	1978	1979	1980	1981	1982	1983
% total requirements	97.8	98.8	99.0	97.5	95.7	97.8	99.1	100.3
% career requirements	89.5	89.4	89.4	92.3	90.2	93.8	95.3	96.4

The same number entered the inventory here as in the last case, so the only thing that has changed is the addition of the bonus.

It can be seen that the bonus will improve manning in both the total and career force, as expected. In fact, the manager now knows that he can get 100 percent manning in the total rating by the end of the planning horizon, with no change in the input plan. However, the number of careerists still falls below that which is required.

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[1] In the EMPPS model (see reference (c)), annual allocations to training are determined using linear programming.

Bonus Contingent Upon Six Year Reenlistment

At this point the manager might consider applying controls on the contract length for those who reenlist under the bonus plan. The redistribution feature of VACATE was used to determine the effect of setting all *first term* reenlistment contracts to 6 years. This was accomplished by changing the EAOS redistribution matrices for LOS 4, 5, and 6. It was assumed that extensions would occur in the same proportion as before and all reenlistees now flow into EAOS 6.

The combined effect of the reenlistment bonus and 6 year contract policy on the projected inventory is shown below:

	1976T	1977	1978	1979	1980	1981	1982	1983
% total requirements	97.8	98.8	99.1	97.7	96.0	98.3	100.1	101.5
% career requirements	89.5	89.6	89.6	92.6	90.7	94.8	97.0	98.6

The career force is projected to come within 99 percent of requirements by the end of the planning period. The total force, however, is projected to be over-manned by 1.5 percent in 1983.

Enlistment Contract Options

Under this option, the rating manager wishes to project the inventory which would result if all (initial) enlistment contracts for those who go to A-school were 6 years.[1] Such a policy is modeled by VACATE as a change in the EAOS distribution describing entrants into LOS 1 and 2 from *future* allocations to the rating. Note that the distributions for those entering the inventory in LOS 1 and 2 are the only ones affected by the new enlistment contract policy. For simplicity, we assume that those who enter the inventory after LOS 2 came from OJT and will not be affected by the new policy. Those who enter into LOS 2 during the first year the policy is initiated come from a previous allocation, and will not be affected by the policy change. The adjusted distributions have 100 percent of those entering in LOS 1 in EAOS 6 and zero in the other EAOS cells, and 100 percent of those entering in LOS 2 in EAOS 5, with zero elsewhere.

The projected inventories resulting from the 6 year enlistment policy are shown below:

	1976T	1977	1978	1979	1980	1981	1982	1983
% total requirements	97.8	97.5	96.7	93.6	90.1	93.0	97.4	98.4
% career requirements	89.5	87.1	94.6	95.7	81.9	88.5	94.0	94.8

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[1]Assuming an adequate supply of recruits.

The results suggest that the projected inventory will fall short of requirements by about 2 percent for the total and 5 percent for the career force in 1983.

Comparison of Results

The rating manager now has 4 sets of inventory projections; one which would result from the current plan, and 3 which would arise from implementing VACATE policy options. Which is the plan he should adopt?

Several criteria could be used to evaluate and compare the 4 plans. These are: cost and feasibility of implementation, and how long it takes to meet or approach requirements. Table 1 compares the 4 plans along one of these dimensions -- meeting requirements by the last year of the planning horizon (FY 83).[1]

TABLE 1

COMPARISON OF INVENTORY PROJECTIONS DURING
FY 83 FOR SEVERAL POLICY OPTIONS

	Policy Option			
LOS	Current plan	Bonus	Bonus with 6 year reenlistment	6 year enlistment contract with A-school
1-31	23888 (93%)[a]	25706 (101%)	26004 (102%)	25216 (98%)
5-31	11523 (83%)	13341 (96%)	13639 (99%)	13123 (95%)

[a]Numbers in parentheses represent percent of requirements.

Inspection of table 1 suggests that the large bonus combined with a six year reenlistment contract policy should produce an inventory closest to requirements by 1983.

CONTINUING EFFORTS

VACATE is in a formative stage. The basic methodology is innovative and rests on a solid foundation; however, more work is needed in refining the data used in modeling the process.

[1]We will not attempt to compare costs. This would require computation of training costs for A-school and OJT which is the subject of a separate, ongoing, study. However, we have held the total number of allocations to training constant for the 4 plans.

Much of the modeling has been influenced by examining histori-
cal inventory flows for only a handful of ratings over a recent
3 year period. This has allowed some preliminary testing of many
of the assumptions regarding flows through the inventory and has
provided some feedback on the stability of various processes.

Assumptions of Stationarity

Earlier we discussed the circumstances under which certain
flows were assumed to remain stationary, or not likely to be affect-
ed by new policy changes. Those flows which are sensitive to policy
can be modeled given the quantitative relationship between the
policy change and the flow parameter in the model (e.g., how bonus
levels affect reenlistments). Two areas of contention arise here --
how do we know that certain processes will remain stationary, and
how valid are the relationships between the proposed policy changes
and the flow parameters?

We can conclude that a process is stationary when we can ob-
serve it, as such, over time. When the process changes, we begin
a systematic search for the variables associated with the change.
In this way we can cope with, i.e., model, dymanic processes. This
suggests a strategy for testing the assumptions of stationarity and
validating the models of changing processes used in VACATE.

Continuing efforts are now being made to measure the stability
of the various data sets used by the model, e.g., continuation rates,
redistribution matrices, and training pipeline flows, at different
points in time. Although this has been accomplished on only a limited
basis, a number of insights have been gained. Three of the most
striking are: (a) continuation rates in EAOS 2 and beyond tend to
be more stable than reenlistment rates (EAOS 1); (b) extensions and
early enlistments result in a significant number of "non-normal" re-
distribution patterns; (c) while flows through the A-school pipeline
can be related to explicit policy variables, such as training plans,
flows through OJT have been difficult to associate with measurable
policy variables. Measuring flows through the training pipeline is
a high priority task and is the subject of a continuing effort.

Of particular importance is the separation of the A-school and
OJT flows. A better understanding of these two flows is necessary
for changes in training allocation policy to be adequately modeled
by VACATE.

Reliability of Data

The example illustrating some of VACATE's capabilities used
a large rating which has about 24,000 men. Inventory projections
for large ratings tend to be inherently more reliable than for small

ratings, say one with fewer than 3,000 men. This is because of the large number of parameters which must be estimated to complete the data base. Analysis of historical inventories of small ratings may not produce reliable estimates of continuation rates for certain LOS-EAOS combinations because of unobserved flows, or a continuation rate of .5 may be the result of one out of 2 people surviving. We are currently trying a number of grouping and smoothing techniques as possible answers to the missing and unreliable data problem.

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